REMARKS

Claims 13-32 are pending in this application. By this Preliminary Amendment, Applicant AMENDS the specification and the abstract of the disclosure, CANCELS claims 1-12 and ADDS new claims 13-32.

Applicant has attached hereto a Substitute Specification in order to make corrections of minor informalities contained in the originally filed specification. Applicant's undersigned representative hereby declares and states that the Substitute Specification filed concurrently herewith does not add any new matter whatsoever to the above-identified patent application. Accordingly, entry and consideration of the Substitute Specification are respectfully requested.

The changes to the specification have been made to correct minor informalities to facilitate examination of the present application.

Applicant respectfully submits that this application is in condition for allowance. Favorable consideration and prompt allowance are respectfully solicited.

Respectfully submitted,

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~~DESCRIPTION~~

Attorney Docket No. 36856.1371

BOUNDARY ACOUSTIC WAVE DEVICE

~~Technical~~Background of the Invention

1. Field of the Invention

[0001] ~~The~~The present invention relates to a boundary acoustic wave device ~~using~~utilizing a boundary acoustic wave which propagates along a boundary between a first medium layer and a second medium layer having a different sound velocity ~~therefrom~~from the first medium layer, and more particularly, ~~relates~~ to a boundary acoustic wave device ~~having the structure to suppress~~which suppresses unwanted spurious signals.

~~Background~~2. Description of the Related Art

[0002] In surface acoustic wave devices ~~using~~utilizing a surface acoustic wave, such as a Rayleigh wave or a first leakage wave, ~~miniaturization~~ reduced size and ~~reduction in~~ weight can be achieved, and in addition, ~~the~~ adjustment is not required.

[0003] ~~Hence, the~~ Thus, surface acoustic wave devices have been widely used for RF or IF filters in, for example, mobile phones, VCO resonators, ~~or~~ and VIF filters for

televisions.

[0004] However, since ~~having properties propagating along a surface of a medium, a~~ surface acoustic ~~wave is~~ waves propagate along a surface of a medium, surface acoustic waves are sensitive to ~~the change in~~ changes in the surface condition of the medium. Accordingly, in a chip ~~through~~in which ~~a~~ surface acoustic ~~wave~~waves propagates, a chip surface along which a surface acoustic wave propagates must be protected. ~~Hence~~Thus, a surface acoustic wave device must be hermetic-ally sealed using a package having a cavity portion therein~~ so ~~, such that the chip surface of the surface acoustic wave chip faces the cavity portion. As a result, the cost of the package ~~as~~ described above is ~~generally~~ relatively high~~, and in~~. In addition, the size of the package ~~becomes inevitably much~~ must be larger than ~~that~~the size of the surface acoustic wave chip.

[0005] ~~As a~~A boundary acoustic wave device, which does not require the package having a cavity portion as described above, ~~a boundary acoustic wave device~~ has been proposed.

[0006] Fig. 15 is a front cross-sectional view ~~and a schematic perspective view showing one example~~ of a conventional boundary acoustic wave device. In a boundary acoustic wave device 101, a first medium layer 102 and a

second medium layer 103 having ~~a~~ different sound ~~velocity therefrom~~velocities are laminated to each other. At a boundary A between the first medium layer 102 and the second medium layer 103, an IDT 104 ~~functioning as~~defining an electroacoustic transducer is disposed. In addition, reflectors (not shown) are disposed at the two sides of the IDT 104 in the direction along which a boundary acoustic wave propagates~~, reflectors (not shown) are disposed~~.

[0007] In the boundary acoustic wave device 101, by applying an input signal to the IDT 104, a boundary acoustic wave is ~~driven.~~generated. The boundary acoustic wave propagates along the boundary A of the boundary acoustic wave device 101, as schematically shown by ~~an~~ arrow B in Fig. 15.

[0008] In "Piezoelectric Acoustic Boundary Waves Propagating Along the Interface Between SiO_2 and $LiTaO_3$" IEEE Trans. Sonics and ~~ultrason~~Ultrason., VOL. SU-25, No. 6, 1978 IEEE, one example of ~~the~~ a boundary acoustic wave device as described above ~~has been~~ is disclosed. In this device, an IDT is formed on a 126° rotated Y plate X propagating $LiTaO_3$ substrate, and a SiO_2 film having a ~~predetermined~~desired thickness is formed on the $LiTaO_3$ substrate so as to cover the IDT. In this structure, ~~it has been disclosed that~~ an SV+P type boundary acoustic

wave~~, a so called~~ (Stoneley wave~~,~~) propagates. ~~In~~ "Piezoelectric Acoustic Boundary Waves Propagating Along the Interface Between SiO_2 and $LiTaO_3$" IEEE Trans. Sonics and ~~ultrason~~Ultrason., VOL. SU-25, No. 6, 1978 IEEE, ~~it has been disclosed~~ discloses that when the thickness of the SiO_2 film is set to 1.0 λ (λ indicates the wavelength of a boundary acoustic wave), an electromechanical coefficient of 2% is obtained.

[0009] ——In addition, in "Highly Piezoelectric Boundary Acoustic Wave Propagating in $Si/SiO_2/LiNbO_3$ Structure" (26^{th} EM symposium, May 1997, pp. 53 to 58), an SH type boundary acoustic wave ~~has been disclosed propagating~~ propagates in a [001]-Si<110>/SiO_2/Y-cut X propagating $LiNbO_3$ structure. This SH type boundary acoustic wave has an advantage in that an electromechanical coefficient k^2 is ~~large~~increased as compared to that of the Stoneley wave. In addition, since the SH type boundary acoustic wave is an SH type wave, ~~it is expected that~~ the reflection coefficient of electrode fingers ~~forming~~defining an IDT reflector is ~~large~~increased as compared to that ~~in the case~~ of the Stoneley wave. ~~Hence~~Thus, when a resonator or a resonator type filter ~~is formed by using~~utilizes the SH type boundary acoustic wave, greater miniaturization can be ~~further~~ achieved~~, and in~~. In addition, ~~it is also expected that~~ steeper frequency properties ~~can be~~ are

obtained.

[0010] Since the boundary acoustic wave devices ~~use a~~utilize boundary acoustic waves, which are disclosed in "Piezoelectric Acoustic Boundary Waves Propagating Along the Interface Between SiO_2 and $LiTaO_3$" IEEE Trans. Sonics and ultrason., VOL. SU-25, No. 6, 1978 IEEE and "Highly Piezoelectric Boundary Acoustic Wave Propagating in $Si/SiO_2/LiNbO_3$ Structure" (26th EM symposium, May 1997, pp. 53 to 58), a package ~~having~~including a cavity portion is not required. ~~Hence, miniaturization of acoustic wave devices and cost reduction thereof can be achieved.~~Therefore, the size and cost of the acoustic wave device are reduced. However, ~~it was first found through experiments carried out by~~ the inventors of the present invention have discovered that, when the boundary acoustic wave device is actually ~~formed, a problem of frequency properties occurs in that~~produced, unwanted spurious signals are ~~liable to be~~often generated.

[0011] Figs. 16 and 17 are views illustrating a problem ~~of~~ with a conventional boundary acoustic wave device~~,~~. Fig. 16 is a schematic perspective view showing the appearance of the boundary acoustic wave device 111, and Fig. 17 is a view showing the frequency properties thereof.

[0012] As shown in Fig. 16, on a Y-cut X propagating

single crystal $LiNbO_3$ substrate 112, an IDT 113 and reflectors 114 and 115 are formed using ~~a~~ an Au film having a thickness of about 0.05 λ. In addition, on the single crystal $LiNbO_3$ substrate 112, a SiO_2 film 116 having a thickness of about 3.3 λ is formed by RF magnetron sputtering at a wafer heating temperature of about 200°C so as to cover the IDT 113 and the reflectors 114 and 115. The number of electrode finger pairs of the IDT 113, the cross width, and the duty ratio of the electrode finger are set to 50 pairs, about 30 λ~~, and~~ and about 0.6, respectively. In addition, the number of ~~the~~ electrode fingers of the reflectors 114 and 115 are each set to 50, and the wavelength λ of the reflectors 114 and 115 ~~are~~ is set to ~~coincide with~~ be substantially the same as the wavelength λ of the IDT 113. In addition, the distances between the center of the electrode finger of the IDT 113 and that of the reflectors 114 and 115 are each set to about 0.5 λ. On the upper and the lower sides of the Au film, thin Ti layers are formed by deposition in order to enhance the adhesion.

[0013] The frequency properties of a boundary acoustic wave device 111 formed as described above are shown in Fig. 17. As ~~can be seen from~~shown in Fig. 17, in the boundary acoustic wave device 111, ~~a plurality of~~ spurious signals ~~having certain intensity is~~are generated

at a higher frequency side which have greater intensities than ~~that~~the spurious signals generated at an anti-resonance frequency and the vicinity thereof.

[0014] ~~—~~Accordingly, when the boundary acoustic wave device 111 is used as a resonator, unnecessary resonance is generated by the spurious signals described above~~, and in~~. In addition, when the boundary acoustic wave device 111 is used as a filter, the out-of-band suppression level is degraded thereby~~; hence, it is understood that~~. Therefore, the spurious signals ~~heavily interferers~~significantly interfere with the production of practical boundary acoustic wave devices.

~~Disclosure of Invention~~

~~In consideration of the conventional techniques~~

SUMMARY OF THE INVENTION

[0015] To overcome the problems described above, ~~an object~~preferred embodiments of the present invention ~~is to~~ provide a boundary acoustic wave device which ~~can~~ effectively ~~suppress~~ suppresses unwanted spurious signals and ~~can obtain~~which provides superior frequency properties.

[0016] ~~—~~In accordance with a first ~~aspect~~preferred embodiment of the present invention, ~~there is provided~~ a boundary acoustic wave device ~~using~~utilizes a boundary acoustic wave ~~which~~ that propagates along a boundary

between a first medium layer and a second medium layer, in which the sound velocity of the second medium layer is ~~low as compared to~~ less than that of the first medium layer, and when the wavelength of the boundary acoustic wave is represented by λ, the thickness of the second medium layer is ~~set to~~preferably at least about 7 λ~~ or more~~. That is, according to the first ~~aspect~~preferred embodiment of the present invention, since the second medium layer having a ~~low~~ relatively ~~low~~ sound velocity ~~is formed to have~~ has a specific thickness, unwanted spurious signals ~~can be~~ are effectively suppressed.

[0017] ——In accordance with a second ~~aspect~~ preferred embodiment of the present invention, ~~there is provided~~ a boundary acoustic wave device ~~using~~is provided which utilizes a boundary acoustic wave ~~which~~ that propagates along a boundary surface between a first medium layer and a second medium layer, in which a structure for scattering an acoustic wave is provided ~~for~~ on at least one surface of the first and/or the second medium layer at the side opposite to the boundary surface therebetween.

[0018] ——In the second ~~aspect~~preferred embodiment of the present invention, since the structure for scattering an acoustic wave is provided, unwanted spurious signals ~~can be~~ are suppressed.

[0019] ——According to one specific ~~case~~example of the

second ~~aspect~~preferred embodiment of the present invention, the sound velocity of the second medium layer is ~~low as compared to~~ less than that of the first medium layer, and the structure for scattering an acoustic wave is provided for the second medium layer.

[0020] According to another specific ~~case~~example of the second ~~aspect~~preferred embodiment of the present invention, the structure for scattering an acoustic wave ~~is~~includes at least one recess portion and/or at least one protrusion portion provided ~~for~~on at least one surface of the first and second medium layers at the side opposite to the boundary surface.

[0021] According to another specific ~~case~~example of the second ~~aspect~~preferred embodiment of the present invention, when the wavelength of the boundary acoustic wave is represented by λ, the depth of the recess portion or the height of the protrusion portion is at least about 0.05 λ ~~or more~~.

[0022] According to another specific ~~case~~example of the second ~~aspect~~preferred embodiment of the present invention, when the wavelength of the boundary acoustic wave is represented by λ, the pitch between the recess portions and/or the pitch between the protrusion portions is at least about 1 λ ~~or more~~.

[0023] According to another specific ~~case~~example of

the second ~~aspect~~ preferred embodiment of the present invention, when the wavelength of the boundary acoustic wave is represented by λ, the thickness of the medium layer ~~for~~on which the structure for scattering an acoustic wave is provided is about 7 λ or less, the thickness of the medium layer being defined by the distance between the boundary surface and the surface opposite thereto. That is, when the thickness of the ~~first~~second medium layer having a low sound velocity is less than about 7 λ, it is difficult to suppress the spurious signals~~; however~~. However, when the structure for scattering an acoustic wave is ~~used~~provided, the spurious signals ~~can be~~are suppressed.

[0024] ~~—~~According to another specific ~~case~~example of the second ~~aspect~~preferred embodiment of the present invention, the second medium layer is ~~composed~~made of SiO_2, the first medium layer is ~~composed~~made of a piezoelectric substrate containing Li, and at least one recess portion and/or at least one protrusion portion is ~~formed~~provided on a surface of the second medium layer ~~composed~~made of SiO_2.

[0025] ~~—~~According to a specific ~~case~~example of the first and ~~the~~ second ~~aspects~~preferred embodiments of the present invention, an electroacoustic transducer for driving a boundary acoustic wave is ~~formed~~ provided

between the first and the second medium layers.

[0026] According to another specific ~~case~~example of the first and ~~the~~ second ~~aspects~~preferred embodiments of the present invention, at least one reflector is ~~further~~ provided at the boundary between the first medium layer and the second medium layer.

[0027] According to another specific ~~case~~example of the second ~~aspect~~ preferred embodiment of the present invention, an exterior layer material is ~~further~~ provided on the surface of the medium layer on which at least one recess portion and/or at least one protrusion portion is provided.

~~Brief Description of the Drawings~~

[0028] Other features, elements, steps, advantages and characteristics of the present invention will become more apparent from the following detailed description of preferred embodiments thereof with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Figs. 1(a) and 1(b) are a schematic front cross-sectional view showing ~~an important~~ a portion of a boundary acoustic wave device ~~of~~ according to a first preferred embodiment of the present invention ~~and a~~

~~schematic perspective view~~ showing the appearance thereof, respectively.

[0030] Fig. 2 is a ~~view~~graph showing a displacement distribution of a main mode of a boundary acoustic wave in conventional boundary acoustic wave devices shown in Figs. 15 and 16.

[0031] Fig. 3 is a ~~view~~graph showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

[0032] Fig. 4 is a ~~view~~graph showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

Fig. 5 is a ~~view showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.~~

[0033] ~~Fig. 6 is a view~~graph showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

[0034] Fig. ~~7~~6 is a ~~view~~ graph showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

[0035] Fig. 7 is a graph showing one example of a displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

[0036] Fig. 8 is a ~~view~~graph showing one example of a

displacement distribution of a spurious mode under the same conditions shown in Fig. 2.

[0037] ——Fig. 9 is a ~~view~~graph showing impedance properties of the boundary acoustic wave device ~~of the first embodiment~~according to the second preferred embodiment of the present invention.

[0038] ——Fig. 10 is a ~~view~~graph showing the change in impedance ratio of a spurious mode obtained when the depth of grooves forming irregularities in the first preferred embodiment is changed.

[0039] ——Fig. 11 is a ~~view~~graph showing the change in impedance ratio of a spurious mode obtained when the pitch between grooves forming irregularities is changed.

[0040] ——Fig. 12 is a schematic perspective view illustrating the structure of grooves of a modified example of the boundary acoustic wave device ~~of~~according to the first preferred embodiment of the present invention.

[0041] ——Fig. 13 is a ~~view~~graph illustrating a second preferred embodiment of the present invention ~~and is a view~~ showing the change in impedance ratio of a spurious mode obtained when the thickness of a SiO_2 film having a relatively low sound velocity is changed.

[0042] ——Fig. 14 is a schematic partial front cross-sectional view showing ~~an important~~ a portion of a boundary acoustic wave device of a modified example of the

boundary acoustic wave device ~~of~~according to the first preferred embodiment of the present invention.

[0043] Fig. 15 is a schematic partially cut-away front cross-sectional view illustrating a conventional boundary acoustic wave device.

[0044] Fig. 16 is a schematic perspective view illustrating a conventional boundary acoustic wave device.

[0045] Fig. 17 is a view showing impedance properties of the boundary acoustic wave device shown in Fig. 16.

~~Best Mode for Carrying Out the Invention~~DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0046] Hereinafter, with reference to figures, particular preferred embodiments of the present invention will be described ~~so~~ such that the present invention will be clearly understood.

[0047] First, in order to investigate the causes of the spurious signals shown in Fig. 17, ~~the~~ a numerical analysis of the boundary acoustic wave device 111 shown in Fig. 16 is performed, ~~so~~ such that the displacement distribution of a boundary acoustic wave and the displacement distribution of a spurious mode are obtained. In this investigation, it is assumed that the displacement between a SiO_2 film and Au and that between the Au and a $LiNbO_3$ substrate are continuous and the stress in the

vertical direction is continuous, the potential is 0 ~~because of~~ due to a short-circuiting boundary, the SiO_2 film has a predetermined thickness, and the $LiNbO_3$ has an infinite thickness.

[0048] Fig. 2 shows the displacement distribution of a main mode of a boundary acoustic wave when the thickness of the SiO_2 film is ~~set to~~preferably about 2.5 λ, and Figs. 3 to 8 show the displacement distributions of respective spurious modes under the same conditions as described above. In Figs. 2 to 8, U_1, U_2, and U_3 represent a P wave component, an SH wave component, and an SV component, respectively, the horizontal axis indicates the displacement normalized by the maximum value, and the vertical axis indicates the depth direction (- side is the lower side).

[0049] As ~~can be seen from~~shown in Fig. 2, ~~it is understood that~~ the main mode of the boundary acoustic wave is an SH type boundary acoustic wave which is primarily composed of an SH type component. In addition, from Figs. 3 to 8, ~~it is understood that~~ the spurious mode can be roughly categorized into two types of modes; one spurious mode is primarily composed of an SH wave component, and the other spurious mode is primarily composed of a P wave component and an SV wave component. The two types of spurious modes propagate along the upper

surface of the SiO_2 film and along the boundary between the SiO_2 film and an IDT, which is made of Au. In addition, ~~it is believed that~~ since a plurality of high-order modes of the above-described two types of spurious modes is generated, many spurious signals are generated, as shown in Fig. 17.

[0050] The boundary acoustic wave ~~device~~device according to preferred embodiments of the present invention was developed in order to ~~achieve the suppression of~~suppress the spurious signals ~~as~~ described above.

~~(~~

First Preferred Embodiment~~)~~

[0051] Figs. 1(a) and 1(b) are a schematic front cross-sectional view and a schematic perspective view, respectively, illustrating a ~~first embodiment of a~~ boundary acoustic wave ~~device~~device according to a first preferred embodiment of the present invention.

[0052] In a boundary acoustic wave device 1, a first medium layer 2 and a second medium layer 3 are laminated to each other. In this preferred embodiment, the first medium layer 2 is ~~formed of~~preferably a Y-cut X propagating single crystal $LiNbO_3$ substrate, and the second medium layer 3 is ~~formed of~~ a SiO_2 film. Between the single crystal $LiNbO_3$ substrate 2 and the SiO_2 film 3,

that is, at a boundary A between the first and the second medium layers, an IDT 4 ~~as~~defining an electroacoustic transducer is disposed. In Fig. 1(a), only a ~~part~~ portion at which the IDT 4 is disposed is ~~only~~ shown~~; however~~. However, as shown in Fig. 1(b), grating type reflectors 5 and 6 are provided at two sides of the IDT 4 in the direction along which a boundary acoustic wave propagates. A film of Au having a thickness of about 0.05 λ is formed on the single crystal $LiNbO_3$ substrate 2, so ~~that~~as to define the IDT 4 and the reflectors 5 and 6~~ are formed~~.

[0053] In addition, after the IDT 4 and the reflectors 5 and 6 are ~~formed~~provided, a SiO_2 film having a thickness of about 3.0 λ is formed at a wafer heating temperature of 200°C by RF magnetron sputtering, thereby forming the SiO_2 film 3.

[0054] The number of electrode finger pairs of the IDT 4, the cross width, and the duty ratio of the electrode finger forming the IDT 4 are ~~set to~~ preferably 50 pairs, about 30 λ, and about 0.6, respectively. The number of the electrode fingers of the reflectors 5 and 6 are ~~set to~~preferably 50, and wavelengths λ of the IDT 4 and the reflectors 5 and 6 are ~~set to coincide with each other.~~preferably approximately the same. In addition, the distances between the centers of electrode fingers of the IDT and the reflectors are each ~~set to~~preferably about 0.5

λ ~~as the distance between the centers of the electrode fingers~~.

[0055] In order to enhance the adhesion, on the upper and the lower sides of the Au film, thin Ti films having a thickness of approximately 0.0005 λ are preferably formed by deposition.

[0056] Next, in an upper surface 3a of the SiO_2 film 3, a plurality of grooves 3b having a depth of about 1 μm is formed by machining so as to ~~have~~ be arranged at an angle of about 30° with respect to the direction in which the electrode fingers of the IDT 4 extend, ~~so~~ such that the boundary acoustic wave device 1 of this preferred embodiment is obtained.

[0057] The impedance properties of the boundary acoustic wave device 1 thus obtained are shown in Fig. 9.

[0058] As ~~can be clearly seen when~~shown in Fig. 9 ~~is~~as compared ~~with~~ to the impedance properties of the boundary acoustic wave device 111 shown in Fig. 17, ~~it is understood that~~ the ~~plurality of~~ spurious responses ~~present~~produced at a higher frequency side ~~than that at the anti-resonance frequency is~~ are suppressed in this preferred embodiment. For example, when a spurious signal generated at 1,300 MHz is represented by an impedance ratio, which is a ratio of the impedance at the resonance frequency to that at the anti-resonance frequency, it is

understood that the spurious signal ~~can be~~ is suppressed from about 22.9 dB to about 6.6 dB, that is, ~~can be~~ the spurious signal is suppressed to about one third.

[0059] ~~The feature of~~In the boundary acoustic wave device 1 of this preferred embodiment~~is that~~, as described above, the grooves 3b are formed in the upper surface 3a of the SiO_2 film 3, which is located opposite to the boundary surface A, so as to ~~form~~ define recess portions. It is believed that ~~by~~ the formation of the recess portions~~,~~ scatters the spurious mode~~is scattered~~, and that the spurious signals are suppressed thereby as described above.

[0060] In ~~consideration~~ view of the results obtained from the above-described boundary acoustic wave device 1, the inventors of the present invention ~~carried out~~ performed further investigation in the depth of the recess portion and the shape thereof.

[0061] In the same ~~way~~manner as described above, the boundary acoustic wave device 1 was formed. However, when the recess portions were formed in the upper surface of the SiO_2 film 3, the grooves 3b were formed so as to ~~have~~ be arranged at an angle of about 45° with respect to the direction in which the electrode fingers of the IDT 4 extend~~ed~~, the grooves 3b ~~being~~ are obtained by forming a resist pattern on the SiO_2 film 3 using a

photolithographic step, followed by wet etching with a diluted hydrogen fluoride solution. By ~~the change~~changing in resist pattern~~,~~ and the ~~change in~~ etching conditions, ~~and the like,~~ the depth of the grooves 3b and the pitch therebetween were ~~variously~~ changed, ~~so~~such that a plurality of types of boundary acoustic wave devices was obtained.

[0062] The impedance properties of the plurality types of boundary acoustic wave devices thus obtained were measured, and in the same manner as described above, the impedance ratios were obtained.

[0063] Fig. 10 is a view showing the relationship between the impedance ratio of the spurious signals obtained as described above and the depth of the groove 3b, that is, the depth of the recess portion. As ~~can be seen from~~shown in Fig. 10, ~~it is understood that~~ the impedance ratio of the spurious signals is improved to about 10 dB or less when the depth of recess portion is at least about 0.05 λ~~ or more~~, and is further improved to about 5 dB or less when the depth of the recess portion is at least about 0.6 λ~~ or more~~. Hence, the depth of the recess portion is preferably at least about 0.05 λ~~ or more~~, and more preferably at least about 0.6 λ~~ or more~~.

[0064] Fig. 11 is a view showing the relationship between the impedance ratio of the spurious signals and

the pitch between the grooves 3b. As ~~can be seen from~~shown in Fig. 11, when the pitch between the grooves 3b is ~~set to~~ preferably at least about 1 λ~~ or more, it is understood that~~, the impedance ratio of the spurious signals ~~can be~~ is improved ~~to~~to about 10 dB or less. ~~Hence~~Thus, preferably, the pitch between the grooves 3b is ~~desirably set to~~preferably at least about 1 λ~~ or more~~.

[0065] In addition, ~~it is also confirmed that~~ even when the angle ~~formed~~ between the groove 3b and the extending direction of the electrode finger of the IDT is ~~set to~~preferably about 0° or about 90°, by forming the grooves 3b so as to have a depth of at least about 0.05 λ ~~or more~~, the impedance ratio of the spurious signals ~~can be~~ is improved.

[0066] In this preferred embodiment, the grooves 3b are ~~disposed in~~arranged to be substantially parallel to each other so as to form a ~~predetermined~~desired angle with the extending direction of the electrode fingers~~, however~~. However, as shown ~~by a~~ in the schematic perspective view of Fig. 12, in addition to the grooves 3b, grooves 3c may be ~~disposed~~ provided in the upper surface 3a of the SiO_2 film 3 so as to intersect the grooves 3b. ~~Also in the case described above,~~ In addition, when the depths of the grooves 3b and 3c are ~~set to~~preferably at least about 0.05 λ~~ or more, it is confirmed that~~, the impedance ratio of

the spurious signals ~~can be~~ is improved as described above.

[0067] ~~—~~In Figs. 1 and 12, in the SiO_2 film, that is, in the upper surface of the ~~first~~second medium, the grooves 3b or the grooves 3b and 3c are formed. However, instead of the linear grooves, curved grooves or grooves having another shape may also be formed. That is, the ~~irregularities in the~~ present invention ~~are~~ is not limited to grooves which are disposed in parallel and which linearly extend.

[0068] ~~—~~In addition, in forming the recess portions, when the depth of the recess portion is ~~set to~~preferably about $\lambda s/4 \times \sin\theta s$ ~~in which~~, where the spurious wavelength and the angle of the above spurious mode incident on the upper surface 3a of the SiO_2 film 3 are represented by λs and θs, respectively, the phase of the spurious signals reflected at the recess portion 3b is opposite to the phase reflected at the upper surface 3a, ~~so~~ such that the above two phases counteract each other. ~~Hence, it is believed that~~Thus, the spurious signals received by the IDT 4 ~~can be~~ are more effectively suppressed.

[0069] ~~—~~In forming the recess portions described above, many grooves 3b are preferably formed~~; however~~. However, when at least one groove 3b is formed, the effect ~~as~~ described above ~~can~~is also ~~be~~ obtained. In addition, instead of the recess portions, protrusion portions in the

form of dots may be provided, ~~and~~or the recess portions and~~/or~~ the protrusion portions may ~~both~~ be provided together.

~~(~~Second Preferred Embodiment~~)~~

[0070] A boundary acoustic wave device ~~of~~according to the second preferred embodiment has ~~the~~ structure that is similar to that of the boundary acoustic wave device 1 ~~of~~according to the first preferred embodiment. ~~Hence~~Thus, description of the boundary acoustic wave device of the second preferred embodiment will be omitted, and whenever necessary, the description of the boundary acoustic wave device of the first preferred embodiment may be used instead. Points of the boundary acoustic wave device of the second preferred embodiment different from the first preferred embodiment are as follows~~, that is,~~: (1) grooves are not provided in the upper surface of the SiO_2 film 3, and (2) the thickness of the SiO_2 film 3 is ~~set to~~preferably at least about 7 λ~~ or more~~.

[0071] That is, in the first preferred embodiment, the irregularities are provided by forming the grooves 3b or the grooves 3b and 3c, and as a result, the spurious signals are suppressed. In contrast to the first preferred embodiment, in the boundary acoustic wave device of the second preferred embodiment, since the thickness of

the SiO_2 film 3 is ~~set to~~preferably at least about 7 λ~~ or more~~, the spurious signals are suppressed. This suppression will be described with reference to particular experimental examples.

[0072] The boundary acoustic wave device 1 was formed in the same manner as that of the experimental example of the first preferred embodiment. However, the irregularities were not provided in the surface of the SiO_2 film 3, and the thickness of the SiO_2 film 3 was ~~variously~~ changed. The relationship between the thicknesses of plural types of boundary acoustic wave devices thus obtained and the impedance ratio of the above spurious mode is shown in Fig. 13.

[0073] As ~~can be seen from~~shown in Fig. 13, ~~it is understood that~~ when the thickness of the SiO_2 film is increased to at least about 7 λ~~ or more~~, the impedance ratio of the spurious mode ~~can be~~ is decreased to about 5 dB or less.

[0074] In the boundary acoustic wave device of the second preferred embodiment,~~ it is believed that~~ since the thickness of the SiO_2 film 3, which is the second medium layer having a relatively low sound velocity and in which an acoustic wave ~~formed into~~producing spurious signals is confined, is sufficiently increased, the spurious signals caused by the above-described acoustic wave ~~can be~~ are

suppressed.

[0075] In addition, more preferably, in the boundary acoustic wave device 1 of the first preferred embodiment, that is, in the structure in which the recess portions and~~/or~~ the protrusion portions are provided for the upper surface of the SiO_2 film, when the thickness of the SiO_2 film is increased as ~~is the case of~~in the second preferred embodiment, the above-described spurious signals ~~can be~~ is more effectively suppressed. ~~Hence~~Thus, preferably, a boundary acoustic wave device ~~is formed having~~including spurious suppression structures according to the first and the second preferred embodiments is provided.

[0076] Fig. 14 is a schematic front cross-sectional view showing a modified example of a boundary acoustic wave device of the present invention.

[0077] In the boundary acoustic wave device 1 of the first preferred embodiment, the recess portions are formed by the formation of the grooves 3b in the upper surface of the SiO_2 film~~; however~~. However, in the case described above, an external layer material 11 may be formed so as to cover the above-described recess portions. When the exterior layer material 11 is formed, although a surface 11a of the exterior layer material 11 is flat, since the irregularities are provided in the upper surface 3a of the SiO_2 film 3 ~~functioning as~~defining the second medium layer,

the spurious signals ~~can be~~are effectively suppressed as ~~is the case of~~in the first preferred embodiment. As the exterior layer material 11, for example, a material such as AlN may be ~~optionally~~ used.

[0078] ~~By the~~ The formation of the exterior layer material 11, improves the mechanical strength of the boundary acoustic wave device~~can be improved, or the penetration of~~ , and corrosive gases ~~can be~~are prevented from penetrating the boundary wave device. That is, since the exterior layer material 11 ~~may function as~~ provides a protective layer as described above, an insulating material, such as titanium oxide, aluminum nitride, or aluminum oxide, or a metal material such as Au, Al, or W may be used for ~~forming~~ the exterior layer material 11.

[0079] In addition, ~~by the formation of the exterior layer material 11, in the case in which~~when the electroacoustic impedance of SiO_2 used as the second medium layer and that of the exterior layer material 11 are significantly different from each other, the formation of the exterior layer material 11, the spurious mode is confined and propagates between the boundary formed by the ~~first~~second medium layer and the exterior layer material 11 and the boundary along which the boundary acoustic wave propagates, ~~the spurious mode is confined and propagates~~ as ~~is the case of~~in a conventional boundary acoustic wave

device. However, even in the case described above, when the recess portions and/or the protrusion portions are formed according to the first preferred embodiment, the spurious mode ~~can e~~ is suppressed.

[0080] ——Furthermore, in the present invention, between the first and the second medium layers, a third medium layer having a sound velocity ~~lower~~less than that of the first and the second medium layers may be provided so as to be used as the boundary layer. In this case, IDT electrodes ~~such as an IDT~~ may be formed between the first and the third medium layers. As described above, ~~also~~ in the structure having the third medium layer, a spurious mode is generated ~~propagating~~ which propagates in the first or the second medium layer at the same time ~~when~~ that the boundary acoustic wave is ~~driven, however~~generated. However, the spurious mode can be suppressed by the formation of the ~~first~~ second medium layer in the same manner as that of the first or the second preferred embodiment. Also in the case in which third and fourth medium layers are formed between the first and the second medium layers, when irregularities are formed at any one of the boundaries between the layers, the spurious mode ~~can be~~ is suppressed.

[0081] ——In the first and the ~~second~~second preferred embodiments, the IDT 4 and the reflectors 5 and 6 are

formed ~~using~~ of Au~~; however~~. However, an electrode material of the boundary acoustic wave device is not limited to Au, and for example, Ag, Cu, or Al may also be used. In addition, in order to improve the adhesion and electrical power resistance of the electrode, a thin layer ~~composed~~ of Ti, Cr, or NiCr may be provided on the electrode layer. In addition, besides resonators, the present invention may be applied to a ~~lateral~~transverse coupling type filter, a longitudinal coupling type filter ~~composed of~~including at least two IDTs and reflectors provided outside the IDTs, a ladder type filter, and a lattice type filter.

[0082] In addition, ~~as a material forming the first and the second medium layers, besides~~ instead of $LiNbO_3$ and SiO_2, various piezoelectric materials may be used to form the first and the second medium layers, such as $LiTaO_3$, $Li_2B_4O_7$, quartz, and titanate zirconate lead-based ceramic, and various dielectric materials, such as glass and sapphire, may also be used.

~~Industrial Applicability~~

[0083] ~~According to~~Since the ~~boundary acoustic wave device of the first aspect of the present invention, since the first~~second medium layer having a relatively low sound velocity has a thickness of at least about 7 λ ~~or more~~, as

can be seen from the above-described experimental example, spurious signals ~~can be effectively suppressed~~ which propagate~~s~~ between the boundary surface along which the boundary acoustic wave propagates and the surface of the second medium layer opposite to the boundary surface are effectively suppressed, and ~~hence~~thus, a boundary acoustic wave device ~~can be provided~~ having superior resonance properties and filter properties are obtained.

[0084] ~~According to the second aspect of the present invention, since~~Since the structure for scattering an acoustic wave is provided ~~for~~ on at least one surface of the first and the second medium layers opposite to the boundary surface along which the boundary acoustic wave propagates, unwanted spurious signals caused by the acoustic wave ~~can be~~are effectively suppressed, and as a result, superior resonance properties and filter properties ~~can be~~are obtained.

[0085] Since the boundary acoustic wave devices ~~according to the first and the second aspects of the present invention use~~utilize a boundary acoustic wave between the first and the second medium layers, a complicated package having a cavity portion is not required, and production ~~can be~~is performed at a ~~reasonable~~reduced cost. In addition, as compared to a surface acoustic wave device, miniaturization and

reduction in weight ~~can be~~are achieved, and ~~hence~~thus, a compact acoustic wave device ~~can be~~ is provided in which high density mounting can be suitably performed.

[0086] ~~According to the second aspect of the present invention, when~~When the structure for scattering an acoustic wave is provided ~~for~~ on the second medium layer, the spurious mode in the second medium layer having a relatively low sound velocity, through which spurious signals are ~~liable~~likely to propagate, ~~can be effective~~is effectively suppressed.

[0087] When the structure for scattering an acoustic wave is ~~formed of~~ defined by recess portions and/or protrusion portions provided on the surface of the medium layer opposite to the surface along which the boundary acoustic wave propagates, ~~by~~ the recess portions and/or the protrusion portions~~,~~ reliably scatter the spurious mode ~~can be reliably scattered~~.

[0088] When the depth of the irregularities described above is at least about 0.05 λ ~~or more~~, or when the pitch between the recess portions and/or the protrusion portions is at least about 1 λ ~~or more~~, the spurious signals ~~can be~~are more effectively suppressed.

[0089] ~~In the second aspect of the present invention, when~~When the distance between the surface along which the boundary acoustic wave propagates and the surface ~~for~~on

20. The boundary acoustic wave device according to Claim 5, wherein a third medium layer having a sound velocity less than the sound velocity of the first medium layer and the second medium layer is provided between the first medium layer and the second medium layer and defines a boundary layer along which the boundary acoustic wave propagates.

ABSTRACT OF THE DISCLOSURE

A boundary acoustic wave device includes a $LiNbO_3$ substrate ~~used as~~defining a first medium layer having a relatively high sound velocity and a SiO_2 film ~~used as~~defining a second medium layer having a relatively low sound velocity, an ~~IDT as an~~ electroacoustic transducer and reflectors ~~are~~ disposed~~,~~ between the first medium layer and the second medium layer, and recess portions and/or protrusion portions provided in the upper surface of the SiO_2 film~~, a plurality of grooves is formed so as to provide recess portions and/or protrusion portions~~.